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Electronic and magnetic behaviors of 2D atom-thin layers: Graphene, black phosphorus, hexagonal boron-nitride and MoS₂

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Two-dimensional (2D) atom-thin layers have attracted significant attention after the discovery of primitive fabrication method of graphene (i.e., mechanical exfoliation of graphite using scotch tapes). As a van-deer Waals engineering, various atom-thin layers and those hybridization are recently studied. In the talk, first, I present magnetism and spintronics arising from edges of 2D atom-thin layers (e.g., graphene, few-layer black phosphorus (BP), hexagonal boron-nitride (hBN), and molybdenum disulfide (MoS₂)). I create nanomesh (NM) structures, consisting of honeycomb like array of hexagonal nano-pores, with specified pore-edge atomic structure (i.e., zigzag type) on individual layers. Interestingly, hydrogen-terminated graphene NM (H-GNM) shows flat-band ferromagnetism, while it disappears in oxygen-terminated GNM (O-GNM). On the other hand, O-BPNM exhibits large ferromagnetism (100 times) due to ferromagnetic spin coupling of edge O-P bonds, whereas it is eliminated in H-BPNM. O-hBNNM also shows large ferromagnetism due to edge O-B and O-N bonds, while it disappears in H-hBNNM. These are also highly sensitive to annealing temperatures to form zigzag pore edge. These open a considerable avenue for realizing 2D atom-thin flexible magnetic and spintronic devices, fabricated without using rare-earth magnetic atoms. Second, I show creation of the world-thinnest Schottky junction on few-layer MoS₂, one of the transition metal dichalcogenides. The 2H-phase of MoS₂ has direct band gaps of 1.5–1.8 eV. It is demonstrated that electron-beam (EB) irradiation to the 2H-phase causes semiconductor-metal transition to 1T-phase and atomically-thin Schottky junction with barrier height of 0.13–0.18 eV is created at the interface of 2H/1T regions. These findings also indicate a possibility that the effective barrier height is highly sensitive to electrostatic charge doping and almost free from Fermi-level pinning when assuming predominance of the thermionic current contribution. This EB top-down patterning opens the possibility to fabricate in-plane lateral heterostructure FETs, which have shown promising scaling prospects in the nanometer range, and/or local interconnects directly with metallic phase (1T) between (2H)MoS₂ transistors, resulting in ultimate flexible and wearable in-plane integration circuits without using 3D metal wirings. Finally, I will also briefly talk about introduction of spin-orbit interaction into graphene by nano-particle decoration.

Biography

Junji Haruyama graduated from Waseda University, Tokyo, Japan, in 1985. He joined Quantum Device Laboratory, NEC Corporation, Japan and worked until 1994. He received PhD in Physics from Waseda University in 1996. During 1995–1997, he worked with the University of Toronto, Canada and also Ontario Laser and Lightwave Research Center (Canada) as a Visiting Scientist. Since 1997, he has been working at Aoyama Gakuin University as a Professor. He was also a Visiting Professor at NTT Basic Research Laboratories, Institute for Solid State Physics, University of Tokyo, and Zero-emission Energy Center, Kyoto University, Japan. He has been also a Principal Researcher at Air-Force Office of Scientific Research (AFOSR), USA, since 2010. He has peer review publications over 100 and four patents, and also invited talks over 150.

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